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Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany

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ABSTRACT

Britain and Germany saw unprecedented growth of variable renewable energy (VRE) in the last decade. Many studies suggest this will significantly raise short-term power system operation costs for balancing and congestion management. We review the actual development of these costs, their allocation and policy implications in both countries.

Since 2010, system operation costs have increased by 62% in Britain (with a five-fold increase in VRE capacity) and remained comparable in Germany (with capacity doubling). Within this, balancing costs stayed level in Britain (–4%) and decreased substantially in Germany (–72%), whilst congestion management costs have grown 74% in Britain and 14-fold in Germany. Curtailment costs vary widely from year to year, and should fall strongly when ongoing and planned grid upgrades are completed. Curtailment rates for wind farms have risen to 4–5% in Germany and 5–6% in Britain (0–1% for offshore and 15–16% for onshore Scottish farms).

Policy debates regarding the balancing system are similar in both countries, focussing on strengthening imbalance price signals and the extent that VRE generators bear the integration costs they cause. Both countries can learn from each other's balancing market and imbalance settlement designs. Britain should reform its balancing markets to be more transparent, competitive and open to new providers (especially VRE generators). Shorter trading intervals and gate closure would both require and enable market participants (including VRE) to take more responsibility for balancing. Germany should consider a reserve energy market and move to marginal imbalance pricing.

1. Introduction

Both the UK and Germany have the declared goal to cut carbon emissions by 80% by 2050 compared to 1990 levels, which requires near-total decarbonisation of the electricity sector. While nuclear and carbon capture and storage (CCS) are plausible low carbon alternatives in the UK, public and political opinion limit Germany's options to renewable energy sources (RES).

Renewable generation has grown dramatically in both countries. Since 2015 29% of Germany's electricity was renewable, as was 24.5% of Britain's [1,2]. The German government aims to source at least 50% of electricity from RES by 2030 [3], and similarly a 45–55% share is needed to meet the UK's Carbon Budget for 2030 [4]. The EU targets at least 27% RES share in total final energy consumption by 2030 [5], which studies suggest would correspond to an electricity share of around 45–55% depending on modelling assumptions [6–8].

The majority of new RES will come from wind and solar [9], since alternatives like hydro and bioenergy are constrained by limited resource and higher cost. Wind and solar are variable renewable energy (VRE) sources: their output depends on weather conditions and so can be forecasted but not fully controlled as can thermal plant. To offset deviations between forecast and actual wind and solar output reserves must be held and operated [10].

VRE capacity has grown significantly in recent years. Combined wind (onshore and offshore) and solar capacity in the UK[1] grew from 5.46 GW in 2010 to 27.25 GW at the end of 2016 [1], while capacity in

Acronyms: BM, Balancing Mechanism; BRP, Balance Responsible Party; BSC, Balance and Settlement Code; BSP, Balancing Service Provider; BSUoS, Balancing Services Use of System; CMA, Competition & Markets Authority; DSM, Demand Side Management; EBSCR, Electricity Balancing Significant Code Review; EEG, Erneuerbare-Energien-Gesetz; EnWG, Energie-Wirtschafts-Gesetz; LoLP, Loss Of Load Probability; PC, Primary Control; RES, Renewable Energy Sources; RMSE, Root Mean Square Error; ROC, Renewable Obligation Certifcate; RoCoF, Rate of Change of Frequency; SC, Secondary Control; STOR, Short Term Operating Reserve; TC, Tertiary Control; VOLL, Value of Lost Load; VRE, Variable Renewable Energy

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[1] Note that throughout this paper, grid related values (e.g. from National Grid) are for Britain, while generation and capacity values (e.g. from BEIS) are for the UK – which includes Northern Ireland. Northern Ireland hosts 3.2% of UK renewable installed capacity, and so the differences are not large.

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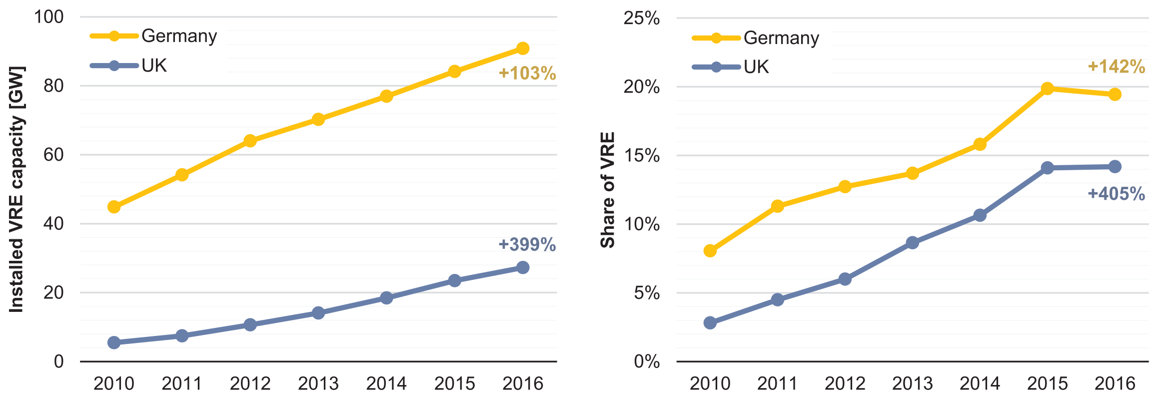

Fig. 1. Development of wind and solar capacity (left) and energy penetration (right), measured as the share of gross inland power consumption; data: [1,11].

Germany increased from 44.84 GW to 90.81 GW [11]. Fig. 1 shows the rise in capacity and penetration.

The cost of wind and solar has declined substantially in the last decade, such that the levelised cost of electricity (LCOE) for onshore wind and large solar is now lower than gas and nuclear [12–14]. However, LCOE does not tell the whole story: To accommodate VRE output while enforcing high standards for security of supply, costs are incurred in other parts of the system, mainly for holding and operating reserve and back up plants to manage variability and uncertainty of VRE output. These are so-called *system integration costs*.

Several studies conclude that electricity systems with high shares of renewable energy (up to 100%) are feasible in industrialised economies without a reduction of security of supply standards [15–17]. Grids have maintained or even increased their reliability during significant increase of VRE penetration (the 'System Average Interruption Duration Index' in Germany went from 18.67 min in 2006 to 10.45 min in 2015) [18,19]. However, decarbonising the electricity sector must be conducted cost-efficiently and would lose public acceptance if it led to a substantial increase of power prices for industry, businesses and residents.

Numerous studies exist on integration costs, mostly based on modelling (e.g. [20–23]). These concur that increasing VRE penetration will lead to increased system operation costs, which could hinder the political feasibility of highly or completely renewable electricity systems. However, the already significant penetration of VRE in Britain and Germany offer an opportunity to study the impacts that VRE integration is actually having on two major industrialised economies based on real market data.

We choose to focus on Britain and Germany for five reasons:

- they are two advanced industrial countries of similar economy and population, climatic conditions, and ambitious climate policies;
- they have comparable conventional power mixes and natural resources, notably limited opportunities for hydro storage and domestic biomass, and a recent increase in renewable generation capacity;
- they currently have a large installed wind capacity, both in terms of % penetration, and especially in terms of GW capacity;
- they are widely anticipated to have the largest installed wind capacities in Europe: for example, the ENTSO-E 2030 Visions see between 30 and 58 GW installed in Britain and 61–101 GW in Germany (together 40–50% of Europe's total wind capacity) [24];
- the transparency of their systems operators and regulators means that substantial quantitative data is available, necessary to perform such a study.

While higher system operation cost due to VRE integration might not yet be observable in retail electricity prices (cp. Appendix D), detailed data on system operation costs are made publicly available by system operators and regulators which we use as evidence on cost impacts of system integration of VRE sources in the UK and Germany. For this reason, we focus on short-term integration costs of VRE sources. In contrast, quantifying long-term integration costs (such as for lower average utilisation of generation capacity) requires scarce data, involves controversy about methodologies and must be based on tentative assumptions about future electricity systems.

Short-term integration costs of VRE broadly consist of two components: grid congestion management and balancing. This paper explores the impacts that VRE is having in the British and German power systems, how related costs are allocated in both systems, how these costs have developed in the last 7 years and the ongoing policy debates in both countries regarding their reduction and cost reflective allocation. We focus mainly on wind over solar, as it is the major VRE technology in both Britain and Germany in terms of electricity generation and has higher impacts on grid congestion and system balancing

The cost of grid congestion, especially compensating curtailed wind output, has gained media attention and fuelled the debate about curtailment management, how risk of curtailment should be shared and how it relates to a changing role of distribution grid network operators [25,26]. However, these costs are a temporary phenomenon that can be reduced by sufficient reinforcement of grid capacities, which is ongoing in both countries. The cost allocation of grid *infrastructure investments*, while being related is another question of great complexity, which is handled very differently in the UK and Germany, and is widely debated in policy, research and industry [27–29]. As this involves long-term considerations and assumptions, it is not discussed here.

We investigate reforms of the balancing system in both countries. This policy debate centres on three topics:

1. setting the right incentives for market participants to contribute to the balance of the system;
2. giving them sufficient possibilities and opportunities to act on these incentives; and
3. reducing balancing costs through improved system operation, including opening balancing markets to new providers, including VRE generators.

Another question is whether integration costs constitute system externalities [22]: Do VRE generators bear the costs that they cause elsewhere in the system to a sufficient extent in current market arrangements? If not, how could market arrangements be changed to internalise these costs?

The next section explores grid constraint costs, their cost allocation and recent development in Germany and Britain. Section 3 compares how system balance is managed in Britain and Germany and investigates cost developments in both countries. Policy options for balancing systems reform are discussed in Section 4. Section 5 then summarises and concludes. The data presented in this paper is available